

CRC

HANDBOOK
of
CHEMISTRY
and
PHYSICS

DAVID R. LIDE
Editor-in-Chief

74TH
EDITION

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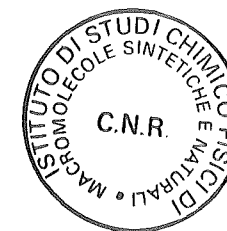
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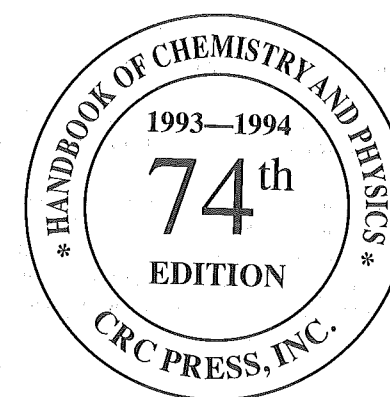
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CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data



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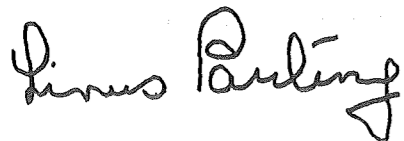
This edition dedicated to the memory of E. Bright Wilson, Jr., an outstanding scientist, educator, a human being, and a lasting inspiration to his students.

FOREWORD

Beginning in 1918 I made much use of my copy of the first edition of the *CRC Handbook of Chemistry and Physics*, continuing with later editions for a total period, until now, of seventy-five years.

Over this whole period I have made great use of the *CRC Handbook of Chemistry and Physics*. I attribute much of my knowledge about substances and their properties to my study of the information that the *Handbook* provided. In particular, I remember that I spent much of my time during five months in the summer of 1919 poring over the tables and thinking about the properties of substances. I was then working as a paving engineer in the mountains of southern Oregon, supervising the work of the contractor who was paving a section of the California-Oregon highway. I had much leisure time and not many books to read, and day after day I found it interesting to think about the properties of substances as described in the *Handbook*, and to wonder if it might be possible to bring some order into the experimental values. I was fascinated in particular by the magnetic properties of substances. At that time I did not know that it was Michael Faraday who had discovered diamagnetism and measured the diamagnetic susceptibilities of many substances. Later, in 1945, when Charles Coryell and I published our observations that the hemoglobin in venous blood is paramagnetic, corresponding to a total of 16 unpaired electrons on the 4 iron atoms, whereas hemoglobin combined with oxygen or carbon monoxide or other ligands is completely diamagnetic, I discovered that Faraday had also measured the diamagnetism of blood, but only of blood combined with oxygen, not of venous blood.

I am pleased that I am able to continue to rely on the information provided by the *CRC Handbook of Chemistry and Physics*, to which I still refer often. I am sure that many other people also find the *Handbook* to be of great value to them.



Linus Pauling
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PREFACE 74th Edition

The 74th Edition of the *CRC Handbook of Chemistry and Physics* contains over 50 new or updated tables. The area receiving the most attention in these revisions is properties of solid materials; examples of the new tables include:

- High Temperature Superconductors
- Optical Properties of Metals and Semiconductors
- Heat Capacity of Selected Solids
- Thermal Conductivity of Metals and Semiconductors as a Function of Temperature
- Thermal Conductivity of Alloys as a Function of Temperature
- Thermal Conductivity of Crystalline Dielectrics
- Hardness of Minerals and Ceramics

Several important tables in the area of atomic, molecular, and nuclear science have been completely updated:

- Strengths of Chemical Bonds
- Electron Affinities
- Atomic and Molecular Polarizabilities
- Nuclear Spins, Moments, and Other Data Related to NMR Spectroscopy
- Summary Tables of Particle Properties

The modernization of the tables on thermodynamic and transport properties has also continued, with new tables on:

- Enthalpy of Fusion
- Enthalpy of Vaporization
- Surface Tension of Common Liquids
- Diffusion in Gases
- Halocarbon Refrigerants

Other highlights of the new edition are:

- Kinetic Data for Combustion Modeling — A list of recommended reaction rates for chemical reactions involved in hydrocarbon combustion
- Atmospheric Electricity — A new review of the basics of lightning and other electrical phenomena in the atmosphere
- Conversion of Temperatures from the 1948 and 1968 Scales to ITS-90 — A table of officially approved values for converting to the new International Temperature Scale
- Standard ITS-90 Thermocouple Tables — Recently-released tables for thermocouple calibration from the National Institute of Standards and Technology

Many other tables have been reset and converted to SI units and modern notation. Furthermore, all errors pointed out by users or detected by other means have been corrected. User feedback is an important step in assuring the high quality of the data in the *CRC Handbook of Chemistry and Physics*. All readers are urged to report errors and inconsistencies.

As Linus Pauling states in the Foreword to this edition, the *CRC Handbook of Chemistry and Physics* has been a definitive source of data on the properties of substances and materials for the last 80 years. The overall philosophy of the *Handbook* remains to provide broad coverage of all types of data commonly encountered by physical scientists and engineers, with as much depth as can be accommodated in a one-volume format. Wherever possible, data for the *Handbook* are selected from evaluated sources rather than the original literature. There is now an extensive body of critical evaluations and reviews in all fields of chemistry and physics. These give comprehensive, detailed tables of data that have been carefully checked by experts. Furthermore, evaluated databases in computerized form, often more voluminous than the printed versions, are growing in number. Clearly, a single-volume reference like the *CRC Handbook of Chemistry and Physics* can include only a tiny fraction of the data found in these specialized collections. Our objective

is to pick and choose from these collections in an effort to provide *Handbook* users with the data they most frequently require. References to the most important sources are given, so that users are directed to other compilations or databases that may give them the answer they seek, even if the *Handbook* itself does not contain the answer.

The contents of the *Handbook* are divided into 16 Sections plus two Appendices. This categorization attempts to place related information together in a logical way. However, any such scheme has certain arbitrary aspects, and what is logical to one reader may appear unnatural to another. Thus a considerable effort has gone into indexing the material so that it can be located easily, whatever terminology seems natural to the user. Comments and suggestions on the Index are welcomed.

The decision on the order in which to list chemical compounds in a table is always difficult. An alphabetical list by name has the disadvantage that several different synonyms are often in common use, with the result that a reader may conclude incorrectly that a compound is not present if he looks it up under the wrong name. Listing by line formula is satisfactory for simple inorganic compounds, but is cumbersome for organics. A listing by molecular formula is attractive because clear rules can be given for locating a compound, but the user may have to go to some effort to determine the molecular formula. In this book the choice is made on pragmatic grounds. If the table is short and includes only common substances, the listing is usually alphabetical by name or, for inorganic compounds, by formula as commonly written. Most longer tables are listed by molecular formula using a modification of the Hill convention. In this convention the molecular formula is written with C first, H second, and then all other elements in alphabetical order of their chemical symbols. For tables with organic compounds only, the sequence of entries then follows the alphabetical order of elements in the molecular formula and the number of atoms of each element, in ascending order, e.g., C_3H_7Cl , C_3H_7N , C_3H_7NO , $C_3H_7NO_2$, etc. In tables containing non-carbon compounds, those are usually listed first, followed by a separate listing of compounds that do contain carbon. This is in contrast to the strict Hill convention as followed by Chemical Abstracts Service, where the molecular formulas beginning with A and B precede the formulas for carbon-containing compounds, while those beginning with D...Z follow. For tabular displays, as opposed to an index, it appears more convenient to the user if the non-carbon compounds are listed as a block, rather than being split by the longer list of carbon compounds. The reader may look up the molecular formula by name or synonym by using Appendix B, which also gives CAS Registry Numbers.

Comments and criticisms from users are very important to the success of this book. Suggestions for new topics which should be covered in the *Handbook* are particularly helpful. Address all comments to Editor, *Handbook of Chemistry and Physics*, CRC Press, Inc., 2000 Corporate Blvd. N.W., Boca Raton, FL 33431.

The *CRC Handbook of Chemistry and Physics* is dependent on the efforts of many contributors throughout the world. The list of current contributors follows this Preface. The members of the Editorial Advisory Board have offered many valuable suggestions. I should also like to express my gratitude to those at CRC Press who look after the health of the *CRC Handbook of Chemistry and Physics*. This includes Christina Martin, James Brody, Barbara Caras, and, in particular, Paul Gottehrer, whose dedication and attention to detail assures the highest quality in production of the book. I also appreciate the able assistance of Lauren Bascom in preparing many of the new tables. Finally, it would be difficult to produce each new edition without the continuing help and support of my wife, Bettijoyce B. Lide.

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